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A feasibility study to determine the structure of an assessment system which would evaluate the effectiveness of JTC3A was conducted. The study determined that a top-down automated decision support system is most suitable. The study also outlined the next steps in the development of such a system.

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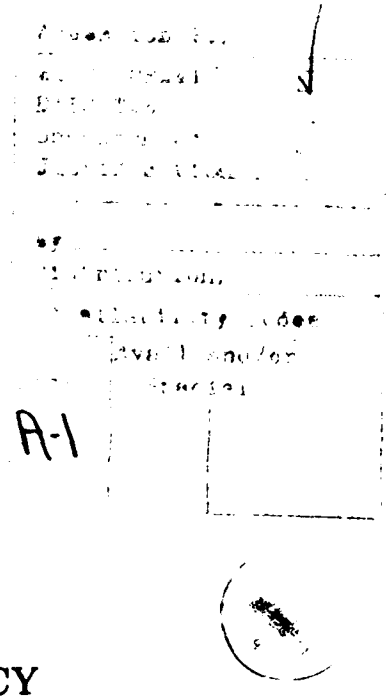
FEASIBILITY STUDY OF DEVELOPING A MEANINGFUL AND IMPLEMENTABLE METHODOLOGY FOR ASSESSING JTC3A EFFECTIVENESS



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EXECUTIVE SUMMARY

The mission of JTC3A is to ensure interoperability of tactical C3 systems employed in joint and combined operations of the US Military. At the present time, there does not exist a systematic way of assessing JTC3A's effectiveness in fulfilling this mission. This feasibility study is the first phase of an attempt to develop a methodology for building an overall assessment system (OAS) which would allow JTC3A to evaluate its effectiveness, and will be helpful in answering questions such as how well is the Agency accomplishing its mission? How could its performance be improved, given a constant level of resources? What would be the effect of a change of resources allocated to the Agency?

To determine the feasibility of developing such a methodology and building the suitable OAS a study of the responsibilities, activities and modes of operation of the Agency was performed. Special attention was given to inquiring into the methods used by the agency in

(i) determining interoperability requirements and assessing their importance;

(ii) making plans and schedules and establishing priorities in addressing these requirements;

(iii) allocating and controlling resources expended in the process of putting in place the systems, procedures and devices needed for satisfying these requirements;

(iv) assessing the effectiveness of the systems, procedures and devices put in place.

This study led us to the following conclusions:

1. A top-down automated decision support system approach appears to be the most suitable for building the OAS needed by the Agency.

2. Such an OAS would require the building of a *needs map database*, specifying overall needs and how they are satisfied both from the user and the Agency's viewpoint, and a *projects database*, specifying the projects of JTC3A and their status. Forerunners of such databases exist at JTC3A (The JIMS and Instant Architecture Data Base).

3. From these databases several meaningful aggregated and disaggregated measures of effectiveness can be computed on a continuous basis.

4. We are confident that JTC3A possesses the necessary talent to develop such a system wholly in-house. The effort would be commensurate to that applied to the development of other JTC3A databases and the decision to do the work wholly in- house or to contract out parts of it depends on the priority given to this project.

5. If the decision is made to construct such an OAS the next steps would be

   (a) An in depth study for determining the measures (indices) to be produced by the OAS.

   (b) Development of criteria and procedures for ranking importance of interoperability links and for determining users requirements satisfaction.

   (c) Obtaining quantitative estimates of amount of data required and ensuing costs.

   (d) Design of the OAS.

   (e) Development of the databases and computer programs.

   (f) Testing and putting the OAS in place.

These steps should not delay the continuation of the development of JIMS and IADB.

INTRODUCTION

The objective of this study is to determine the feasibility of using existing methodologies and/or developing new ones, for assessing the effectiveness of JTC3A in attaining its mission of ensuring the interoperability of tactical C3 systems employed in joint and combined operations of the US Military. If feasible, an "assessment system" would allow JTC3A to evaluate its effectiveness in attaining its objectives. It will be helpful in answering questions such as how well is the Agency accomplishing its mission; how could its performance be improved, given a constant level of resources, and what would be the effect of a change of resources allocated to the Agency.

Section 1 of the study lists the main capabilities required from JTC3A in accomplishing its mission. The actual way in which each of these functions is now addressed is analyzed in Section 2. Goals of the study are detailed in Section 3 and this leads to a list of questions to be answered concerning JTC3A's objective, the measurement of how well it is attained, required data, possible methodologies and building of an assessment system. Section 4 addresses the choice of a methodology by considering two main approaches: "bottom-up" and "top-down" analysis, and then examining which Operations Research and Management Science techniques appear to be the most likely to satisfy the Agency's needs, (and which ones do not appear to be promising). Based on this analysis, an outline of an overall interoperability and effectiveness assessment system is presented in Section 5. This assessment system, based on a top-down approach to assessment of interoperability measures, requires three main components: (a) a "map" of interoperability needs of the U.S. Military (in the form of an automated database), (b) a database of all JTC3A projects and (c) a collection of procedures for using (a) and (b) to obtain the desired measures. Possible effectiveness and interoperability measures are further discussed in Section 6 together with their feasible uses. Conclusions regarding the feasibility of such an interoperability assessment system and its development are drawn in Section 7. A list of the next steps to be taken should the decision be made to develop such a system completes the study.

1. OBJECTIVE OF JTC3A

The overall objective of the Agency is to ensure the highest possible level of interoperability of tactical C3 systems employed in joint and combined operations of the US Military.[1]

The attainment of this objective requires the Agency to have the capability to:

(a) Determine present and future needs of C3 interoperability of the overall Military system;

(b) Assess the importance, urgency and feasibility of satisfying each of the needs;

(c) Prioritize and devise plans and schedules for addressing these needs;

(d) Control and allocate the resources for developing the means required in the process of putting in place the systems, procedures or devices necessary for satisfying these needs;

(e) Scrutinize and assess the degree of satisfaction of needs achieved by the systems, procedures or devices after they are put in place;

(f) Evaluate its own effectiveness and its impact on overall interoperability.

These required capabilities are discussed in detail in Section 2.

[1]In this report C3 includes intelligence unless otherwise specified. C3I will not be used. Also interoperability will be used to mean interoperability of tactical C3 systems employed in joint and combined operations.

2. A SHORT OVERVIEW OF THE PRESENT STATE OF JTC3A.

Recently the Agency went through a rather comprehensive organizational restructure, and it is still in a transitional mode, in the sense that it did not reach a new steady state free of the impacts due to the organizational changes. Therefore the short overview provided here may not represent accurately the steady state mode of operation that may be reached in the not too far ahead future. The following overview follows the categories of Section 1.

(a) The determination of interoperability needs comes from several sources:

- **(a1)** development of CINC architectures which entail a systematic study of requirements. The product is a detailed description and assessment of C3 interoperability needs at all echelons of the operations of the CINC;
- **(a2)** development of functional architectures addressing nine tactical functional areas each divided into up to 16 sub-areas. These are more generic in nature than CINC architectures and the products, which are intended to be used as building blocks in tailoring CINC and other types of C3 architectures, include descriptions and assessments of C3 interoperability needs across a very wide range of operations;
- **(a3)** interoperability assessments of CINCs master plans. Reviews of CINCs contingency and operations plans, service requirements documents, equipment and emerging technologies and representation in standing boards and panels dealing with joint and combined operations;
- **(a4)** aggressive assignment of AOs to participate in meetings and discussions of issues that may involve interoperability aspects;
- **(a5)** requests from outside the Agency, that may take in some cases the form of tasking.

It is worthwhile mentioning that the automated Joint/Combined Issue Management System (JIMS) which has recently been put into operation is

a useful aid in reporting identification of new needs, among other important types of services that it provides. Other automated systems that may aid in the process of identifying needs are the Instant Architecture Data Base, IADB, (needlines database) being developed by ARM in Reston, the ROC-requirements database and the CINC IPS database.

(b & c) Formally, assessment of importance, urgency and feasibility, and prioritizing, is well taken care of by two well defined processes. The first is a JCS program for annual review, coordination and resolution of critical C3 interoperability requirements and issues (Tactical C3 Interoperability Improvement Program - IIP) performed by a General/Flag Officer Prioritization Board and an O-6 level Screening Board. All services, CINCs and Agencies take part in this program and are represented on these boards. The Director, JTC3A is the Executive Agent for this program. The goals, responsibilities and procedures are described in JTC3A circular 3101. In summary it is clear that the intent of the program is to enable identification of needs, to achieve coordination in funding, fielding and all other aspects, and to agree on priorities.

The second formal process is the Agency's Issue Resolution Process (IRP) as described in JTC3A Instruction 3102 of March 1990. This process is controlled by the Issue Resolution Board (IRB) and Screening Panel. In summary the IRB is responsible for assessing all C3 interoperability issues/deficiencies identified by the Agency and for briefing recommended courses of action to the Director and Associate Director for their approval. The Issue Resolution Process is supposed to be aided by JIMS in identifying new issues/deficiencies and in monitoring changes in status of old ones. In effect the IRB is supposed to "determine the priority of resolving/taking action on each issue. This is an important step as the IRB must recommend to the Director, JTC3A whether resources need to be reprogrammed to address an issue as well as to establish a prioritized listing of all issues which need resources in order to be fully addressed". (JTC3A Instructions 3102).

Our impression concerning (b & c), formed by interviews with Agency personnel, is that evaluation of importance and urgency of the needs

is mostly decentralized. Ranking of the issues to be addressed is done mostly at the level of the directorates, where the Deputy Director is responsible for preparing the ranking list and matching it with the directorate resources in order to decide where to put the cutting point. The ranked lists are scrutinized by the Director to ensure reasonable ranking and then brought before the Resource Allocation Committee (RAC) where some fine tuning adjustments are decided upon. RAC is a top echelon committee (Director, Chief of Staff, Associate/Deputy/Assistant Directors).

(d) The Agency's organizational structure is definitely designed to accommodate the three major activities namely: standards, interoperability assurance (including architectures) and testing/certification. The resources at the disposal of the Agency are determined by the executive and legislative branches of the U. S. government. Once approved, the Agency seems to have a rather high degree of autonomy in allocating its resources and is also not banned from asking for matching funds or even complete financial sponsoring for some specific requests coming from without. However the common case is for a project to be supported from the budgeted resources of the Agency. One of the three major activities where the flexibility in allocation and deployment of resources is more limited is the testing/certification activity. This is due to the requirement that all equipment must be certified and thus tested. The effectiveness of this activity should essentially be measured by its operational efficiency and quality level achieved.

(e) There does not seem to exist at present a single organ responsible for this feedback required capability in the Agency. This is not to say that most or even all the needed information is not within reasonably easy reach of the Agency. AOs are in most cases aware of what actually was implemented, and to what degree, as far as their own projects are concerned. We were unable to identify an in-place commonly used procedure for reporting this information in a standardized form to a central data bank, automated or otherwise.

(f) The Agency is involved in a relatively large number of projects at any point in time. At the present time the Agency does not have at its disposal tools for evaluation of its overall performance in terms of overall

effectiveness and contribution to interoperability of the U.S. Military. This is not to say that conventional procedures, such as Annual Reports and the like are not in place.

One step towards an overall self-assessment system has been already taken in the form of JIMS which is an automated system enabling the Agency to obtain summary information about all issues treated by the Agency. This system is accessible to practically all levels of the organization and is updated on a continuous basis. It allows to easily identify the issues needing more urgent attention and it has the capability to provide quantitative summary information in the form of graphs and numbers. It is also a useful tool that can be used on a day-to-day basis by all levels of the organization in identifying ongoing and finished projects and issues related to their own work. This system is quite new and is still developing. It may prove to be useful as one element in an overall assessment system, if such a system is to be built. A second promising system is the Instant Architecture Data Base being developed by ARM in Reston. This system when completed is designed to store information on needlines, to identify feasible equipment strings, check for certification and be used as an automated tool in Architecture development. When successfully completed it may also serve as a major building block in an overall assessment system. Two other automated systems that may prove to be useful for that purpose are the ROC and CINC IPS databases.

3. GOALS OF THIS STUDY

Although JTC3A commits considerable resources towards improving the level of C3 interoperability, no systematic way of assessing its effectiveness exists at the present time. This "feasibility study" is the first phase of an attempt to develop such a methodology. An "assessment system" would allow JTC3A to evaluate its effectiveness in attaining its objective. It will be helpful in answering questions such as how well is the Agency accomplishing its mission? How could its performance be improved, given a constant level of resources?

What would be the effect of a change of resources allocated to the Agency? A possible second phase would be the development and implementation of the methodology identified in the first phase, provided such a methodology exists or may be developed.

In order to answer the above questions this study considers:

1) The objective of JTC3A and how and to what degree it may be defined in an operational way.

2) How can the extent to which the objective (or a subobjective) has been achieved be measured or otherwise determined.

3) What data are available regarding the JTC3A activities with direct impact on its main objective in the short run, and what data are available which influence its main objective in the medium or long run.

4) What additional data should be obtained, and from what sources.

5) What existing methodologies could be used in an overall assessment system. Should a new methodology be developed? Which methodology appears to be the most promising one?

6) What are the main steps in the development of an overall assessment system implementing that methodology.

7) Could such a system be developed by JTC3A.

4. CHOICE OF A METHODOLOGY

JTC3A has a single, well-defined major mission, i.e. to improve the level of interoperability of US Military tactical C3 systems used in joint and combined operations. However, the JTC3A activities which contribute to the achievement of this goal are numerous and diverse. Obtaining an operational

definition of level of interoperability and estimating this level is a complex task involving large amounts of data. Moreover, the time dimension appears to be a crucial one as a number of Agency activities, rather than addressing present C3 interoperability needs, are geared at improving future interoperability effectiveness, when technology now planned or in the development phase will become operationally available.

One possible approach to assessing JTC3A "effectiveness" would be a "bottom-up" one: Agency activities would first be partitioned with a sufficient amount of detail into homogeneous categories (e.g. designing functional or CINC architectures, planning communications for anti-drug joint and combined operations, etc.) for each of which a subobjective could be defined. Then for each of these categories of activities an assessment method would be developed to estimate the level of attainment of the subobjective (e.g. number of Mil standards developed, percentage of times a commercial standard could be used). Finally, the degree of attainment estimates for the various activity categories would be aggregated into an estimate of global degree of attainment. Such an approach has some advantages. The efficiency of some activities of JTC3A can be estimated using standard methods (e.g. industrial engineering techniques for the Test Center). Criteria for other activities which reflect a major Agency and/or DoD concern might be adopted (e.g. the degree to which commercial standards can be used instead of Agency ones). However, there are also some considerable difficulties. Namely it would be hard to answer the two following questions: (i) how should estimates of attainments and efficiency levels for the various activities be translated in a meaningful way into an overall measure of effectiveness, (ii) how could these estimates be used to find how to increase effectiveness with the given amount of resources or to estimate what would be the effect of a change in level of resources on effectiveness? The bottom-up approach focuses on the question of measuring "how well the Agency is doing what it is doing". This is an introspective approach which, if successfully implemented, will measure efficiency rather than effectiveness, where efficiency is defined as effectivity of operational performance and effectiveness is defined in terms of impact on the interoperability of the U. S. military system.

Another approach to assessing JTC3A effectiveness would be a "top-

down" one: the need for interoperability, would first be established in sufficient detail both for the present and for the near future (i.e. impact of new needlines, of new technologies both on the US and Allies and on the opponents side would be evaluated); then measurements would be made (following criteria to be discussed below) of the degree to which the actual interoperability needs are satisfied and estimates devised for the value of this measure in the near future. The evolution of these figures in time would constitute an aggregate measure of Agency effectiveness. Then the impact of the various Agency activities on unsatisfied present needs and on likely to be unsatisfied future needs would be studied. This would give a tool to improve effectiveness with the present level of resources by changing priorities of various projects of the Agency, as well as to evaluate the impact on effectiveness of changes in level of resources. The top-down approach focuses on the interoperability needs of the military system and attempts to measure the impact of what the Agency is doing on the overall "interoperability level". It is effectiveness, rather than efficiency, oriented.

Such an approach, if possible to pursue and implement, would answer the main questions discussed in Section 3. Its feasibility is analyzed in more detail in the next Sections.

Assuming a top-down approach to effectiveness assessment is chosen, the next question is how formal should such an approach be? Is it reasonable to use mathematical modelling to a large extent? Could some existing "hard" O.R. methodologies be brought to bear or should the effectiveness assessment system be closer to an interactive *Decision Support System*?

In the remainder of this Section, conclusions regarding O.R. methodologies are stated and briefly explained.

Mathematical Programming (Linear, nonlinear and stochastic) models have been used extensively to solve resource allocation problems. Such models are useful when (i) sufficiently precise and measurable data on the effectiveness of activities and the unit amounts of resources they use are known (possibly in the form of probability distributions) including their change pat-

tern in time; (ii) when the levels of activities may be fractional and (iii) the objective function expressing effectiveness, and constraints expressing use of resources have additional properties making the problem solvable by current algorithms (e.g. they are linear in each variable in linear programming). The very large amount of data required, its rapid changing in time, the fact that many activities must be done entirely or not at all, and that the objective function expressing effectiveness could have a difficult to handle form render this approach unattractive.

Research and Development projects selection models and methods which often use mathematical programming in 0-1 variables do not suffer from allowing fractional implementation of projects, but all other difficulties cited above remain.

Multiattribute Utility Theory can in principle be used to rank projects judged along several dimensions. It does not seem to apply well to complex constrained problems such as the one considered here. Moreover, when there are several relevant dimensions eliciting the utility function it is very difficult and sometimes arbitrary in practice.

Methods of *Multiple Criteria Decision Making* (e.g. the Analytical Hierarchy Process and Electre Methods), also consider discrete sets of projects to be ranked or categorized. While none of these does seem comprehensive enough to accommodate the JTC3A effectiveness problem, due to its size and the interactions between individual projects, they could be useful as decision aid tools for solution of important subproblems with a strong impact on JTC3A effectiveness. One such instance would be project selection in the RAC.

In conclusion, it does not appear that any existing O.R. hard methodology is adequate for expressing the overall problem of maximizing JTC3A effectiveness, and simultaneously estimating its present level and how it can be improved by reallocation of resources. The decision support system methodology, in which information stored in a database, or in linked databases, summarized by various statistical techniques and constantly updated, is made

available to decision makers, seems to be much more promising.

5. OUTLINE OF AN OVERALL INTEROPERABILITY AND JTC3A EFFECTIVENESS ASSESSMENT SYSTEM

The purpose of the overall assessment system (OAS) is to provide aggregated measures of the interoperability state and the Agency's effectiveness within a reasonably short time, whenever required. The level of aggregation determines the dimensionality of the measures. Ideally, at the uppermost aggregation level these measures are uni-dimensional, namely, overall interoperability is measured by one number and overall effectiveness is measured by one number. At lower levels of aggregation the measures may take the form of vectors or matrices (tables) of numbers. The Agency may desire an OAS with a capability of providing assessment at more than one level of aggregation.

A uni-dimensional measure enables sharp determination of improvement or deterioration in the measured organization and a simple plotting of its evolvement in time enables to determine in a glance positive or negative trends. The deficiency of such a measure is its fuzzy meaning. A unidimensional measure is actually an index composed of several factors (unidimensional lower level measures) each measured in different units. The aggregation of these factors into one index involves subjective elements or, at best, a rather crude representation of their real weights. A multi-dimensional measure is more precise and meaningful since each factor is represented individually. Such a measure contains more accurate information but may be less sharp in determination of overall change and trends.

The OAS outlined here is based on the top-down approach to assessment of the measures of interest. For such an OAS to be operative it is required that the three following major components be in place.

(a) An updated "map" of interoperability needs of the U.S. military (in the form of an automated database).

(b) An easily accessible database of all completed, ongoing and scheduled JTC3A projects.

(c) A collection of procedures (software) for using (a) and (b) to produce the desired assessment measures at various aggregation levels.

(a) NEEDS

The overall military machine can be viewed as a large collection of communicating entities (nodes), some of which exist on an ongoing basis and some planned to come into existence if and when some foreseeable or unforeseeable situations develop. An interoperability needline (or link) is a pair of such nodes, not belonging to the same service, agency or country, which have a communications connectivity need for exchanging information for performing their functions on a permanent basis, or in case that some specific conditions develop. The needs graph is defined as the set of all nodes and their interoperability needlines (links or arcs). When complete information is attached to each link this network becomes the map of interoperability needs. It should be noted that although the needs graph for the U.S. is quite large, the needs map to be maintained in an automated database is not prohibitively large since the majority of needlines are generic and may exist in all or most CINCs in identical form.

The essential information required for each needline is:

1. Type of functions for which information exchange is required.

2. Preferred and actual modes of communications, such as voice, data, teletype, facsimile, video or any combination therein. Information on specific parameters should also be specified when relevant. Modes which

are critical should be so marked. Other modes desirability should be ranked.

3. Generic or CINC/Agency/Taskforce specific classification. (generic or specific identification code).

4. Security and ECCM requirements.

5. Existing and/or feasible equipment strings.

6. Existing and/or possible message format, protocols and operating procedures.

7. Existence of standards and specifications.

8. Existence of certification.

9. Dependence on other links. A link may be operative but still of little contribution to interoperability if its usefulness is conditional on a set of one or more other links being operative. Full interoperability in such a case is achieved when all links of the interdependent set are operative. The interdependent set must be specified.

10. Importance of the link. This can be of ordinal form, e.g. a categorical rank on a predetermined set, starting from desired and ending at critical. The importance of the link must reflect mainly the expected potential overall damage/loss due to its non- operability.

11. Present satisfaction of interoperability requirements from the user's viewpoint (user's operability number UON). This is recommended to be a simple representation of the present state. Either (1 - nonoperative, 0 - operative) or (1 - nonoperative, 1/2 - partially operative, 0 - operative).

12. Future UON. A forecasted UON over the predetermined future time horizon of the OAS.

It should be noted that most of the needlines information on the map must relate to the present status and to the forecasted status over a predetermined planning time horizon. Forecasts must bring into consideration

technological developments and innovations by the U.S. and its allies and by its potential foes as well as probable political changes and developments affecting the missions, organizations and priorities of the U.S. military.

The needs map database can serve to assess a variety of measures of overall interoperability and as an aid in the assessment of the Agency's effectiveness and the potential contribution of added resources.

A simplistic example is a users overall deficiency (non- interoperability) index (UODI). By multiplying each needline UON by its importance rank (assuming importance is ranked numerically) and summing over all the needlines (and correcting for interdependence) we obtain a uni-dimensional measure of deficiency. If there are no interoperability deficiencies this measure (index) will take the value zero, and will increase in value as the interoperability level deteriorates. At each point in time it is possible to have a curve of overall deficiency measure starting at that point and ending at the OAS time horizon. As mentioned earlier such an index is of the uppermost aggregation level with the advantages and disadvantages as mentioned.

(b) JTC3A Projects Data Base

The essential information required for each project is

1. Description, classification and identification of the project.
2. Needlines affected.
3. Starting time and expected successful completion time.
4. Resources used and expected resources expenditure to completion.
5. Estimated probability of time and degree of implementation when completed.

6. Status of completed projects (e.g. abandoned, completed but not implemented, completed and partially implemented, completed and fully implemented, completed and expected to be implemented at some specified future time, etc.)

7. Other information not required by the OAS but needed for the other uses of this database.

Here as in the needs map database, the information should relate to the present time and to future expectations, whenever relevant. From the viewpoint of the OAS structure there is no need to separate the needs map database from the projects database. However the later may serve as a very effective tool in monitoring and controlling the ongoing activities of the Agency at both the micro and the macro levels and should possess a stand alone capability.

The projects database, in combination with the needs map database, enables the Agency to assess the overall military system and the Agency's roll from more than one viewpoint. While as the users index of non-interoperability is valid and very meaningful from the users point of view, it does not provide the complete interoperability picture. A military operation launched at a specific point in time, whether planned or unexpected, will have to make do with all the deficient needlines at that time. This may result in increased costs, in casualties and material, in time delays, or in impairment of the operation. The user must thus be concerned with the present deficiencies of the needlines involved. The information, for example, that a certain major deficiency is about to be rectified in three months time is an important part of the interoperability picture but is much less relevant to the user whose needs are at present.

A complementary index is an Agency overall deficiency index (AODI). Here we may use for each needline an Agency operability number (AON) between 0 and 1, where AON = 0 means 100% operative, AON = 1 means non-operative and no project for rectifying the deficiency is either underway or scheduled. An AON number between 0 and 1 represents the percent of the

remaining process for eliminating the deficiency. This will be calculated from the data of (b3), (b4) and (b5). The AODI is computed in the same way as the UODI using the AONs instead of the UONs. Since for each needline the AON $\leq$ UON then AODI $\leq$ UODI. The AODI is a measure of the overall deficiency which brings into consideration the resources and time expended by the Agency in rectifying needlines deficiencies weighted by the importance of the needlines. These weighted expended resources equal in fact to UODI minus AODI. (Note that the above described AODI is suitable for the case where the UON can take only the values 0 or 1. If the UON is also allowed to take the value 1/2, for partially operative, the value of the AON, must be normalized multiplying it by the UON value).

The UODI and AODI are brought here mainly as an indication of possible types of measures. We shall not further analyze their properties at this stage. An outline of possible types of producible measures and their uses is presented in Section 6.

(c) PROCEDURES

The purpose of the procedures, in the form of standard software packages (e.g. DBASE) and specially tailored computer programs, is to enable to maintain and update the databases, to access the necessary information for the construction of the various aggregated measures, to produce these measures and present them in the desirable formats and to create a user friendly flexible system which can be expanded to provide useful byproducts upon request.

6. OUTLINE OF POSSIBLE EFFECTIVENESS AND INTER-OPERABILITY MEASURES

In this Section we present outlines of several possible measures. The purpose is not to provide an exhaustive description of all, or even of most, possible useful measures. Rather, we try to provide a sense of types of measures which can be produced by the suggested OAS.

(a) Measures of Non-interoperability

In the previous Section, we described two uppermost aggregation level measures of deficiency, namely, the UODI representing the user's viewpoint and the AODI containing more information and representing the hidden potential due to Agency's effort. Both of these measures are uni-dimensional. Multi- dimensional measures (indexes) are produced by breaking down the deficiencies into several categories, each of particular interest. One example is breakdown by main cause of deficiency:

- new needs
- outdated equipment
- architecture (missing or incomplete)
- standard (incomplete or not accurate)
- testing and certification (shortage or inadequacy)
- low priority (budget consideration)
- disagreement between services/agencies/other organizations
- other.

Clearly causes of deficiency in any specific needline are not necessarily mutually exclusive, as several factors may be involved in causing any one specific deficiency. The breakdown here is by main cause, where secondary causes may be mentioned. Thus we divide our total map into a number of mutually exclusive and exhaustive subsets each characterized by the main cause of deficiency. It is possible now to use the UON numbers and the importance ranks and produce a UODI for each one of these subsets. These must sum to the total UODI. The percentage contributed by each cause is the ratio of UODI of this cause divided by the total UODI. This will give a relatively clear picture of which are the causes that contribute most to non- interoperability. AODI can be calculated in a similar manner.

As mentioned earlier these multi-dimensional measures are more meaningful in the sense that each component represents one factor. However a change over time in such a measure may not always be obviously categorized as positive or as negative since some components may improve and some may deteriorate. It is also possible to produce statistics by secondary causes given the main cause. Such measures are of a lower level of aggregation. Other examples of possible breakdowns are:

- breakdown according to CINCs/Task Forces/Allies;
- breakdown according to pairs of services (there are four services which produce six possible pairs such as Navy/Army, Navy/Air Force, etc.)

Many other possibilities exist and the Agency will have to decide which are of sufficient interest and usefulness to be calculated.

(b) Measures of Effectiveness

On the face of it, the measures of non-interoperability do not reflect the Agency's contribution to the system. However, we have already remarked on

the fact that the difference between the UODI and the AODI is actually a representative of the efforts invested by the Agency in unresolved deficiencies at any given point in time.

There may be several approaches to assessing and monitoring the overall Agency's effectiveness. One way is by noting that every time the Agency completes a project successfully (successfully includes implementation in the field) the gap between the UODI and the AODI decreases (the magnitude of this decrease equals to the UON number multiplied by the importance rank and summed over all the affected needlines). To measure the contribution of the Agency we select a reference date, say January 1. For this date we calculate the UODI from the needs map database. We then forecast the UODI over a period of time (say one year) by using the information in the projects database to estimate the expected time of completion of ongoing projects and the probability of their success. At the end of this period of time we can calculate the actual UODI of the reference needs map (excluding new needlines) and then compute the difference between the actual and forecasted (actual minus forecasted) indices. A zero difference is interpreted as 100% effectiveness in execution of the ongoing and planned projects (this does not indicate, however, if the allocation of resources in the form of projects selected for execution was optimal to begin with). If the difference is positive then the effectiveness is less then 100% and can be numerically calculated. Symmetrically if the difference is negative the effectiveness is more than 100%.

In the next time period the same process is repeated with the reference needs map including the new needlines which were added during the previous time-period. (Note that in the case of drastic changes in the needs map or the resource allocation the time period must be terminated and a new time period started). Over several time periods it is possible to identify a trend in the execution effectiveness of the Agency. It is also possible to calculate the estimated contribution for each time period by the decline of the actual UODI. However, the meaning of the units in which this contribution is measured is somewhat fuzzy.

As mentioned, the above procedure will not provide information about the effectiveness of allocating resources in an optimal or even only a good way. The resources should be allocated to projects with highest expected returns, where the return is measured by the total impact per dollar invested in this project on the overall interoperability. Impact per dollar is calculated as follows: the theoretical impact is the expected magnitude of reduction in the UODI divided by the total budget allocated to the project assuming that the project is completed 100% successfully. This theoretical impact must then be averaged by the success probability distribution to obtain the expected impact. All the required information should be available since it is contained in the two databases. In a near-optimal allocation the projects are ordered according to decreasing expected impacts except for the few lowest priority projects near the cutting-point, where it may be necessary to deviate from the order for the purpose of keeping within the available budget and other resources.

If the need arises to compare several plans of resource allocation it is possible to compute the expected future impact of each plan on the total UODI or on lower level of aggregation UODIs. A comparison of the resulting forecasts may help in identifying the best plan or in ranking the plans. This may be of use at the level of strategic planning involving decisions to change the allocation of resources between areas of activity (standards, architectures, testing and certification, overall monitoring of the needs of the military system, feedback flow enhancement, etc.).

Other measures of effectiveness are possible and the ones to be used are subject to the Agency's preferences.

(c) The Impact of Resource Changes

The impact of changes in resources can be measured in terms of forecasted expected change in the overall interoperability (e.g. the UODI) and/or in its components. Increasing or decreasing resources without change in policies

and priorities will essentially affect the lowest priority projects. Frequently resource changes are a result (or a cause) of changes in DoD policies or priorities. In such cases the needs map database must be updated to reflect the new information and all projects must be re-ranked. The calculated expected impact on the overall interoperability will reflect both resource and policy changes.

At the close of this section it is worthwhile pointing out that effectiveness does not necessarily imply efficiency at the micro level. The OAS is a tool intended for macro assessment of effectiveness in use and allocation of resources. The efficiency of performance at the individual projects level cannot be assessed by the OAS. Here the assessment tools are conventional efficiency studies using industrial engineering methods, and there is no escape from breaking down individual projects into the collection of activities and phases involved and studying these for possible efficiency improvements.

7. FEASIBILITY

While the proposition of developing a quantitative OAS based on "hard" Operations Research and Decision Sciences methodologies is rather questionable we find the decision support system approach much more suitable for the Agency's needs. Thus we rule out the possibility of developing a highly structured optimization system as being non-practical and concentrate on the feasibility of a system with features as outlines in Section 5. For such a system the feasibility issue breaks into two questions:

(1) Is it feasible to assemble all the required information, organize it in the databases, develop the necessary non-standard software and maintain the system on a permanent ongoing basis?

(2) Assuming the answer to (1) is positive, is it feasible to extract from this system meaningful measures of overall effectiveness and interoperability?

Of the two questions, the first one is the more crucial, since question (2) is addressed in some detail in Section 6. Here we focus mainly on the feasibility of developing and operating the OAS.

(a) Needs Map Database

The first step in developing the needs database has already been taken by the Agency in the form of the Instant Architecture Data Base being developed by ARM in Reston. The main sources for identifying both nodes and arcs of the needs graph are the functional and CINC architectures, both available from within the Agency. Some CINCs prefer to do their plans on their own. The Agency, however, is responsible for reviewing all C3 systems requirements and master plans which can provide the Agency with access to information necessary to complete the needs map.

The major missing category of information is the importance of each link (Section 5, (a)1). As this is determined mainly by the consequences of the need not being satisfied, the information should be obtained by expert ratings (e.g., Delphi Method). This involves opinions from without the Agency and will require establishing a formal non-voluntary procedure, (one possibility is the IIP).

The construction of the needs map database is a major undertaking. Nevertheless, the efforts involved are not an order of magnitude greater than those required for developing the Instant Architecture Data Base. In our preliminary estimate, if only joint tactical operations are considered, it is possible to complete the development and testing of the needs database within an 18 months time frame.

(b) The Projects Database

This is actually an extension of the JIMS system which is already operative. All the necessary information, in addition to the JIMS information, is available from within the Agency. Information on status of completed projects (Section 5, (b)6) may require the institution of standard procedures for feedback information as defined and described in Section 1, (e). A decision must be made as to how frequently should the status of each type of projects be updated. Should it be updated periodically or at completion points of pre-determined phases of the project. Estimated probabilities of completion times and degrees of implementation may be obtained by expert judgments combined with the historical data on completed projects stored in the database. The degree of detail of the information and accuracy of estimates is to be determined by the desired types of indices (measures) required from the OAS.

The construction of the projects database and its maintenance is, in our opinion, well within the capability of the Agency. The completion time of such a project is estimated as being significantly shorter than the completion time of the needs map database.

(c) Procedures

Most of the needed procedures (software programs) are included in the standard database package to be used by the Agency. The special additional programs, to be determined by the features required of the OAS, are rather straightforward and do not require high mathematical skill or understanding of elaborate algorithms. The Agency does have the talents needed for either developing the required software in-house or supervising its development by an outside contractor.

In conclusion we are quite convinced that a development of an OAS

along the lines suggested in this study is well within the capability of the Agency. The work can be done in-house completely or partially. This depends less on the availability of in-house talents and more on the priority given to such a project and the urgency of its completion. Use of outside contractors may significantly shorten the completion time of the system.

As for question (2), examples of possible meaningful measures of overall effectiveness and interoperability are outlined in Section 6. The issue here, in our opinion, is not the question of feasibility, it is the question of which measures are desired versus the cost involved in collecting, storing, managing and updating the necessary information for producing these measures. In general, the lower level of aggregation measures (indices) require finer, more detailed, breakdown of the data. This will be reflected in the development and management cost of the OAS.

(d) Implementation

Assuming the Agency decides to develop an OAS of the type suggested in this report we recommend that the following next steps be taken:

(1) An in depth study for determining the measures (indices) to be produced by the OAS, bringing into consideration the need and usefulness of each measure, transparency of its meaning to the Agency and other possible users, ease of producing it, additional data (cost) required for producing it, resulting byproducts and its inter-relations to other measures. This study should also define the data to be maintained in the two databases.

(2) Development of criteria and procedures for ranking importance of links and for determining users requirements satisfaction, as defined in Section 5. This step should be taken simultaneously with step 1.

(3) A quantitative study for estimating (i) the amount of data collection and processing required for initiating and maintaining the system, (ii) the

one time initiation investment costs and (iii) the ongoing maintenance costs.

(4) Design of the OAS (databases, computer programs and procedures for collecting, managing and updating the data).

(5) Development of the databases and the computer programs and collection of the required data.

(6) Testing.

(7) Putting the OAs into use.

These steps should not delay the continuation of the development of the JIMS and Instant Architecture databases with a view of integrating them in the design of the OAS. This will require coordination of the teams involved in the three projects (JIMS, IADB, OAS) since the OAS will incorporate the JIMS and IADB and at the same time will enhance their usefulness as operational tools.

The option of stopping the development of the OAS should be maintained, at least through the completion of step (3). Should the amount of required data and resulting costs turn out to be prohibitive or should determining the measures of interests be found an elusive task (which we do not expect to be the case), the option to abort before committing the bulk of the resources must be open.

(e) Alternative Systems

It is possible to develop more modest and restricted assessment systems which will require considerably less resources in terms of both investment and maintenance costs. The most viable such system will be based on the bottom-up approach as outlined in Section 4. This report does not elaborate on the outlining of such an alternative system. At a meeting with the Director

and a group of high echelon Agency personnel, which took place on August 10, 1990, it became quite clear that, if feasible, a top-down based OAS is preferred.